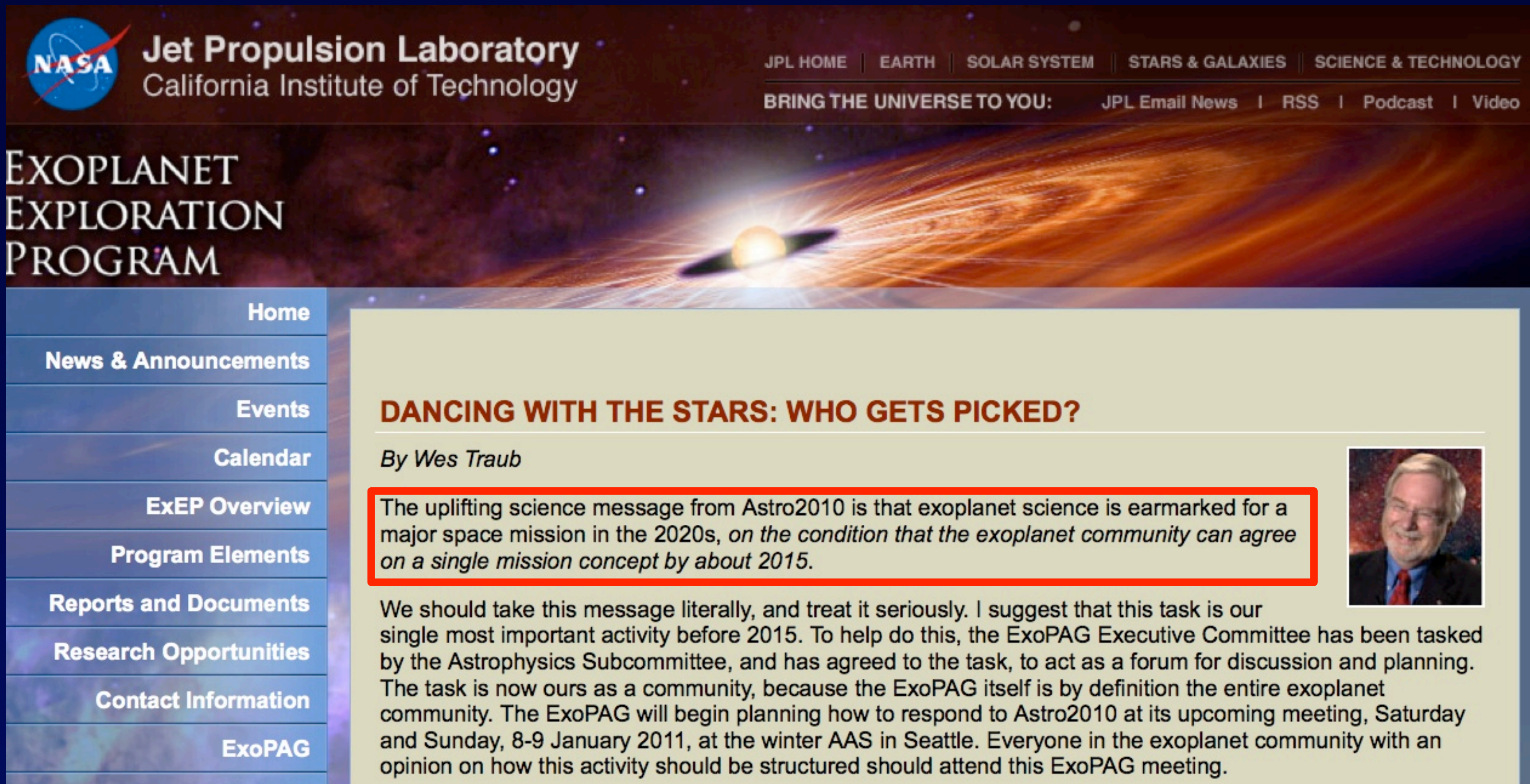
ATLAST:
Advanced Technology Large-Aperture Space Telescope

Technology Developments needed to build an AFFORDABLE 8m - 16m UV/Optical Filled-Aperture Space Telescope

Marc Postman, STScI

ExoPAG Meeting, Seattle, WA

January 8-9, 2010



"… if technology developments of the next decade show that a UV-optical telescope with a wide scope of observational capabilities can also be a mission to find and study Earth-like planets, there will be powerful reason to build such a facility." – Astro2010 EOS** Panel Report.

"… on the condition that the broad astronomical community can agree on a single UVOIR observatory concept by about 2017 …"

**Electromagnetic Observations from Space

Is There Life Elsewhere in the Galaxy?

Need to multiply these values by η_{Life} to get the number of potentially life-bearing planets detected by a space telescope.

η_{Life} = fraction of stars with Earth-mass planets in HZ that also have detectable biosignatures.

If: $\eta_{Life} \sim 1$ then $D_{Tel} \sim 4m$

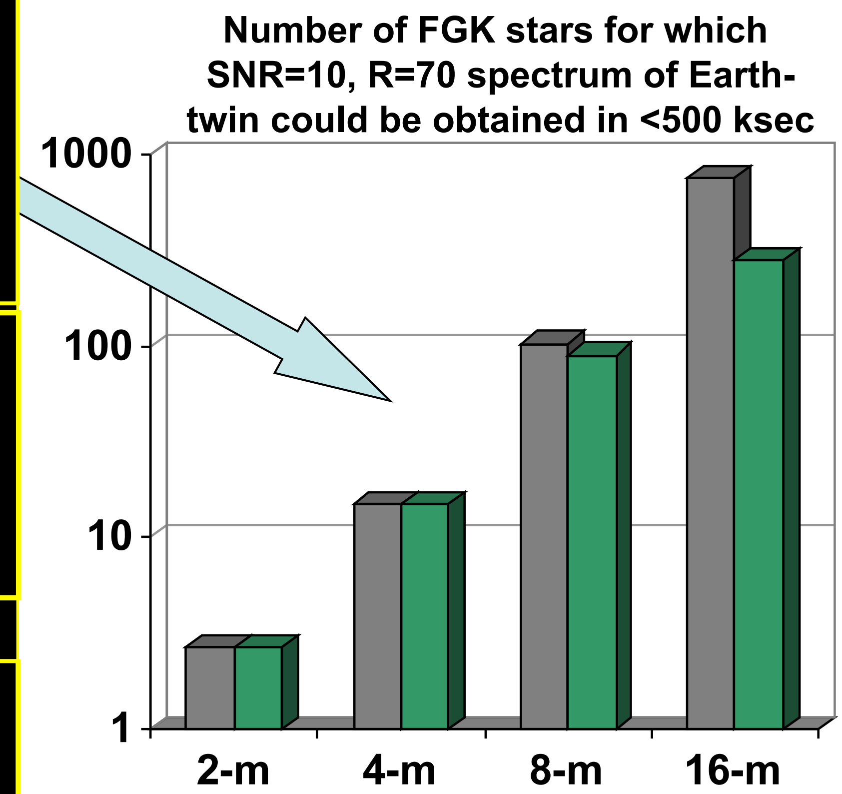
$\eta_{Life} < 1$ then $D_{Tel} \sim 8m$

$\eta_{Life} << 1$ then $D_{Tel} \sim 16m$

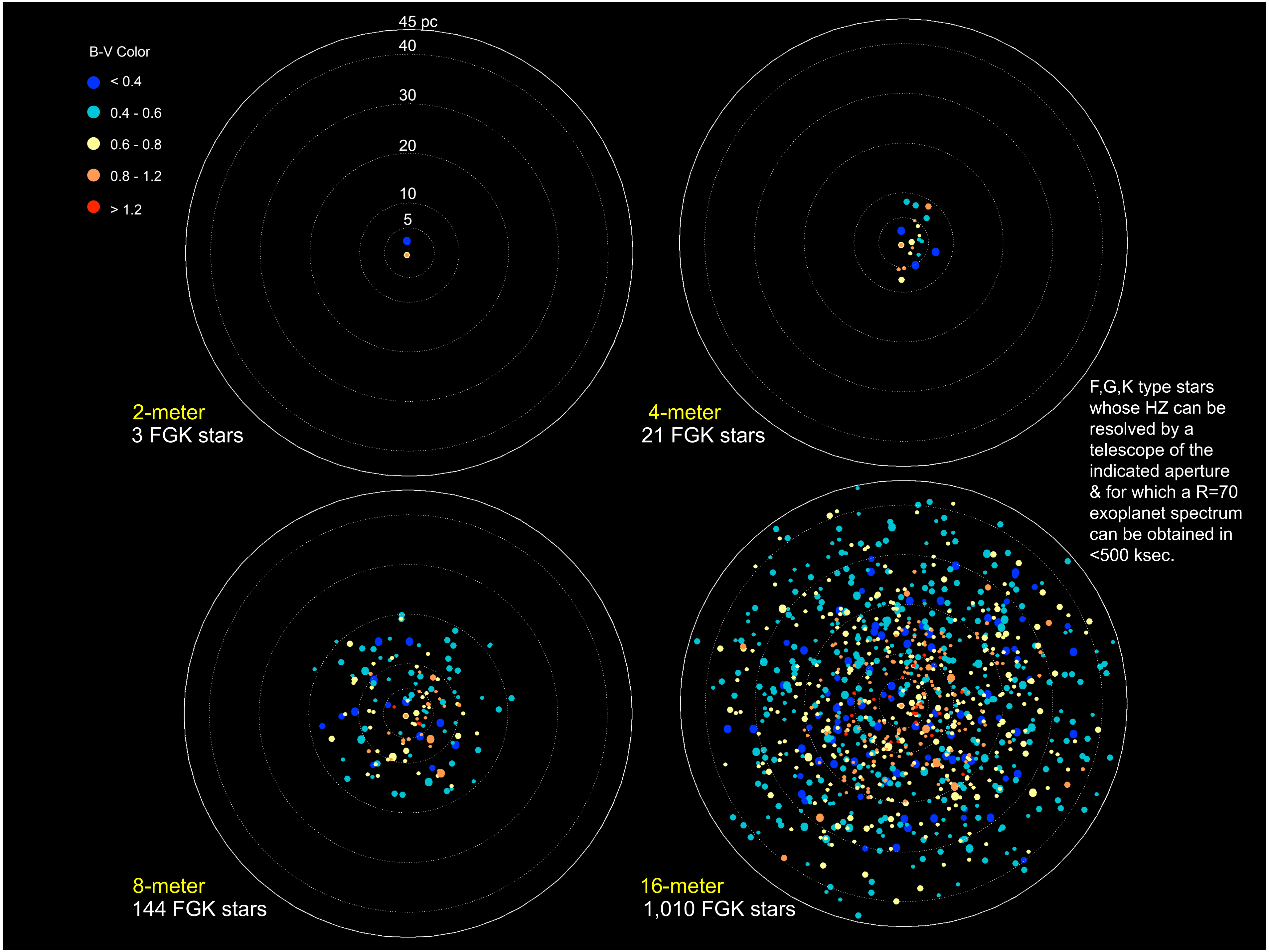
Number of nearby stars capable of hosting

Do you feel lucky?

even a handful. Sample size $\propto D^3$



Green bars show the number of FGK stars that could be observed 3x each in a 5-year mission without exceeding 20% of total observing time available to community.



B-V Color
< 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.2
> 1.2
45 pc
40
30
20
10
5
2-meter
3 FGK stars
4-meter
21 FGK stars
8-meter
144 FGK stars
16-meter
1,010 FGK stars
F,G,K type stars whose HZ can be resolved by a telescope of the indicated aperture & for which a R=70 exoplanet spectrum can be obtained in <500 ksec.

Exoplanet system ages

(Reid et al. 2007)

Known exoplanet hosts are younger on average than field stars, and predominantly younger than the Sun.

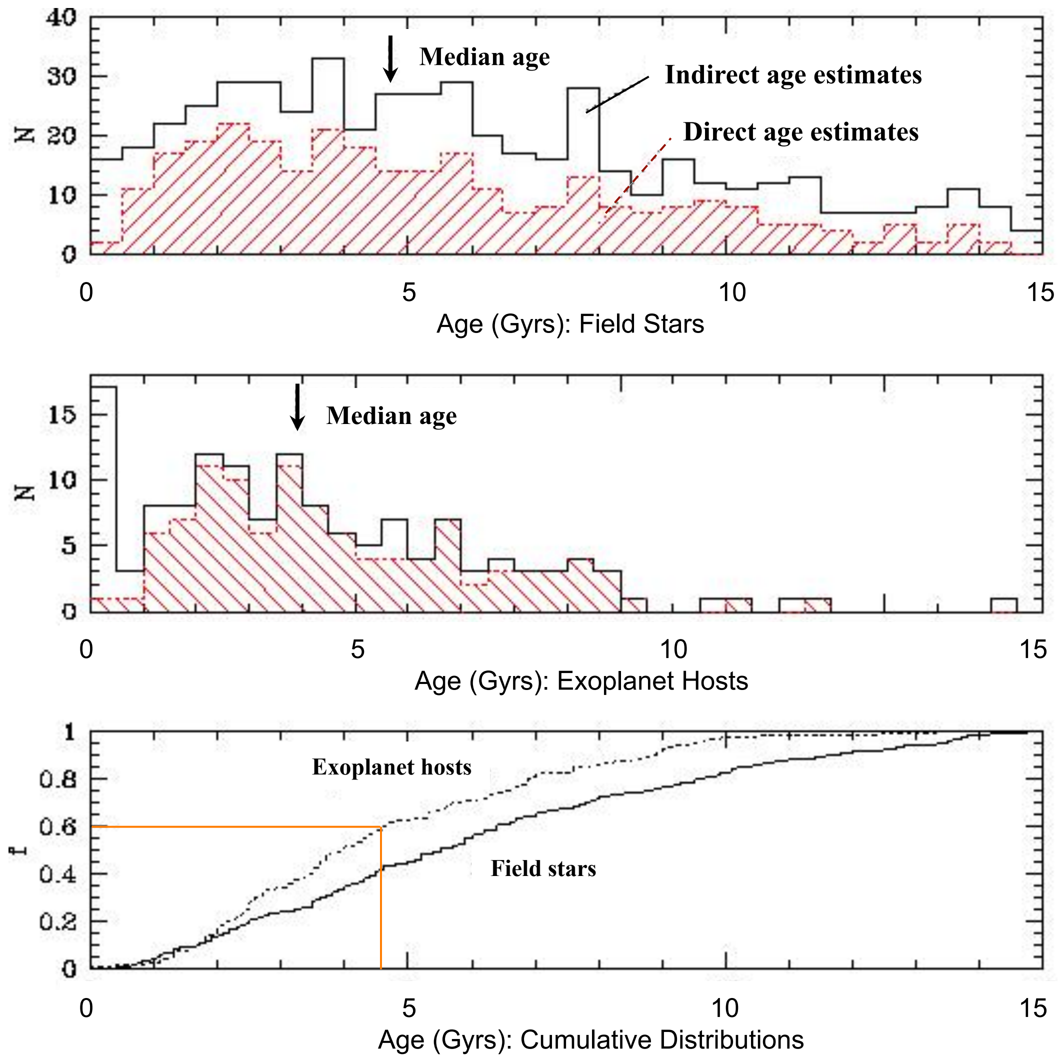
<t> ~ 4.7 Gyrs, field stars

<t> ~ 3.9 Gyrs, host stars

Free O_2 in Earth's atm began ~2.7 Gyr ago. Vegetation (and hence red edge) only within last ~700 Myr.

"Young Earths" are likely to have significantly different spectral characteristics.
(e.g., Kaltenegger, Traub, & Jucks 2007)

Surveys for analogs of present-day Earth need to take such evolutionary effects into account.

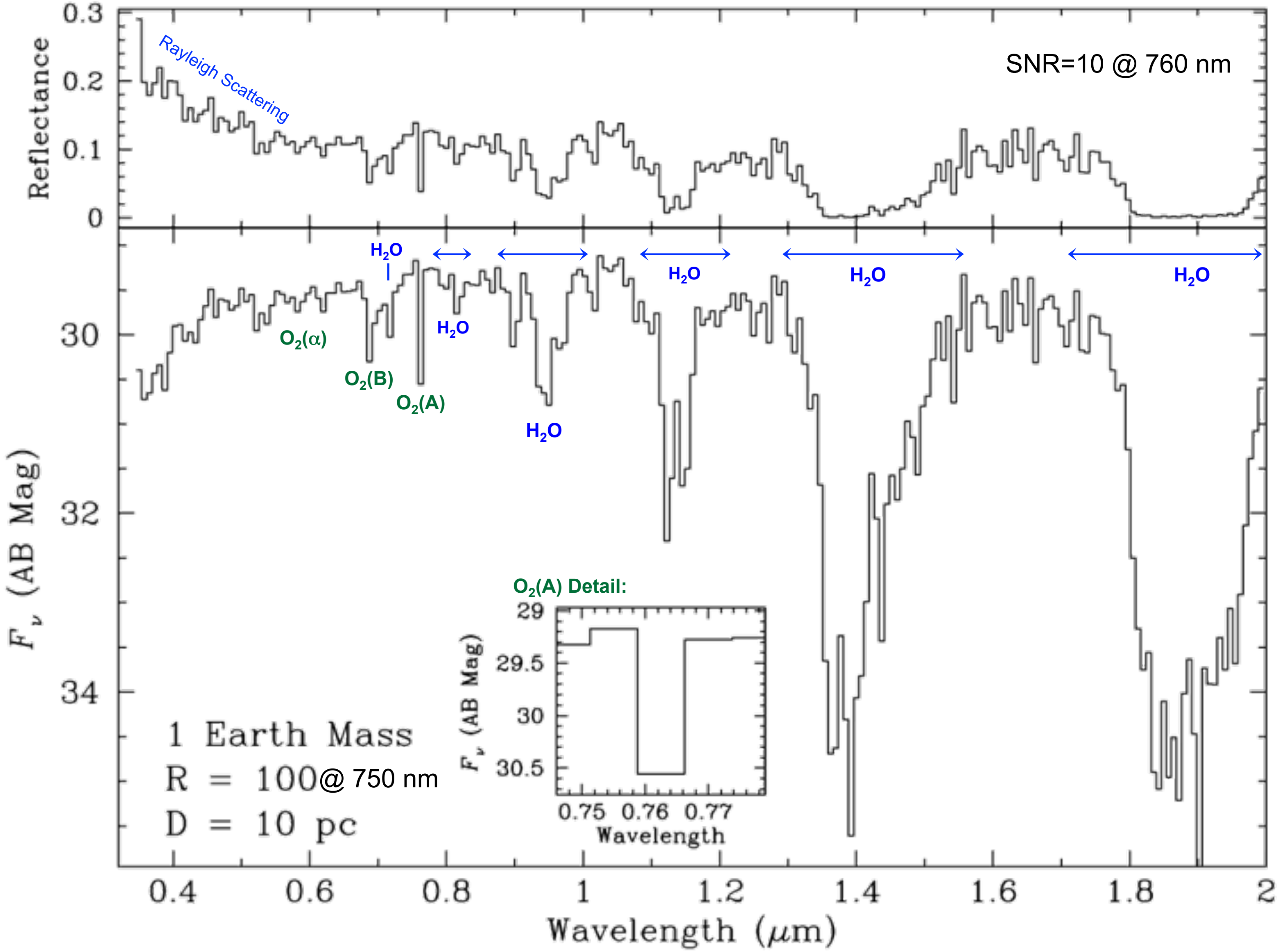


R=100 ATLAST Spectrum of 1 Earth-mass Terrestrial Exoplanet at 10 pc

Exposure: 45.6 ksec on 8-m
7.8 ksec on 16-m

Reflectance ∝ (Planet Mass)$^{2/3}$
5 Earth-mass: 15.6 ksec on 8-m

Bkgd: 3 zodi
Contrast: 10^{-10}

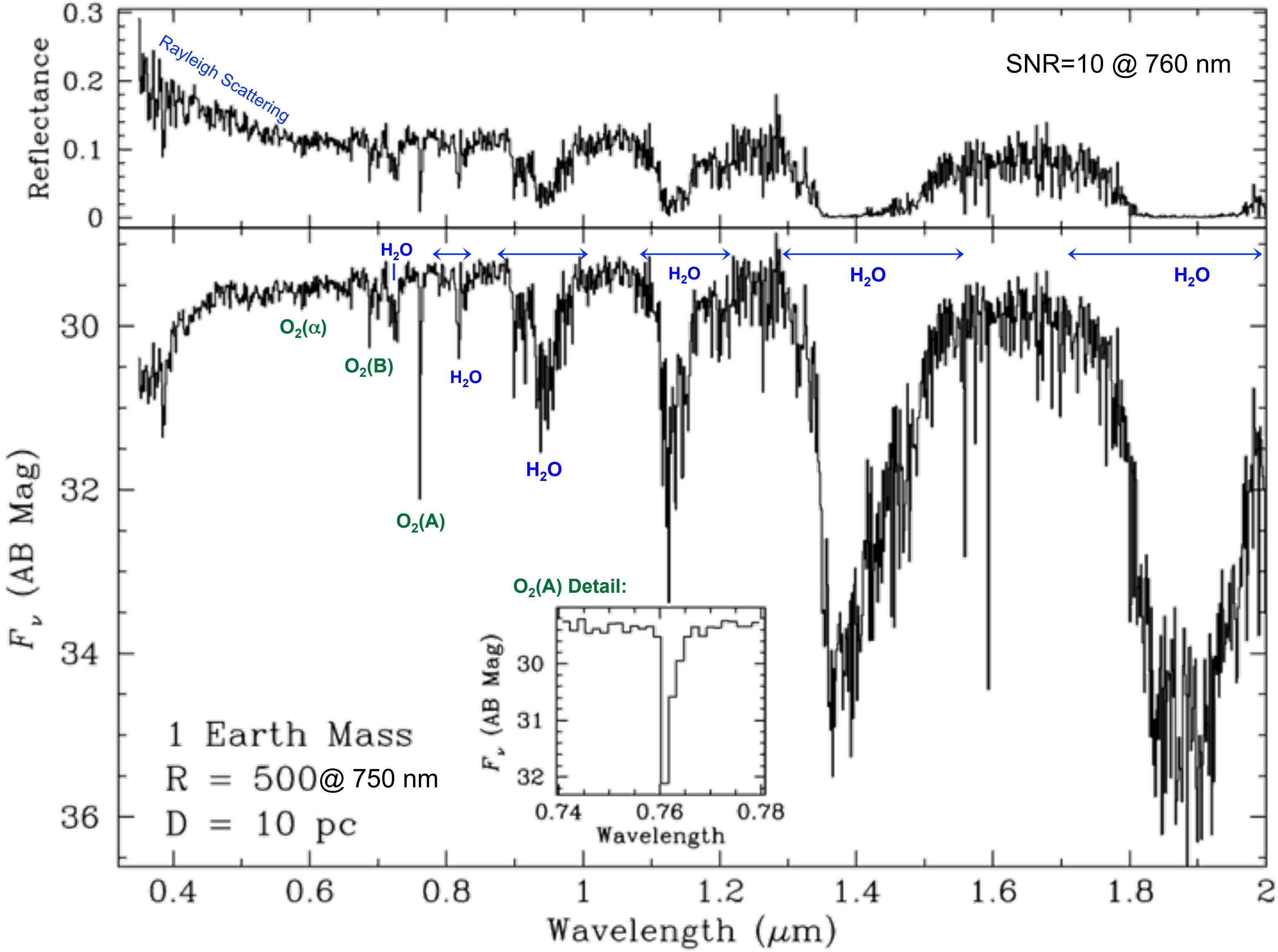


R=500 ATLAST Spectrum of 1 Earth-mass Terrestrial Exoplanet at 10 pc

Exposure: 503 ksec on 8-m
56 ksec on 16-m

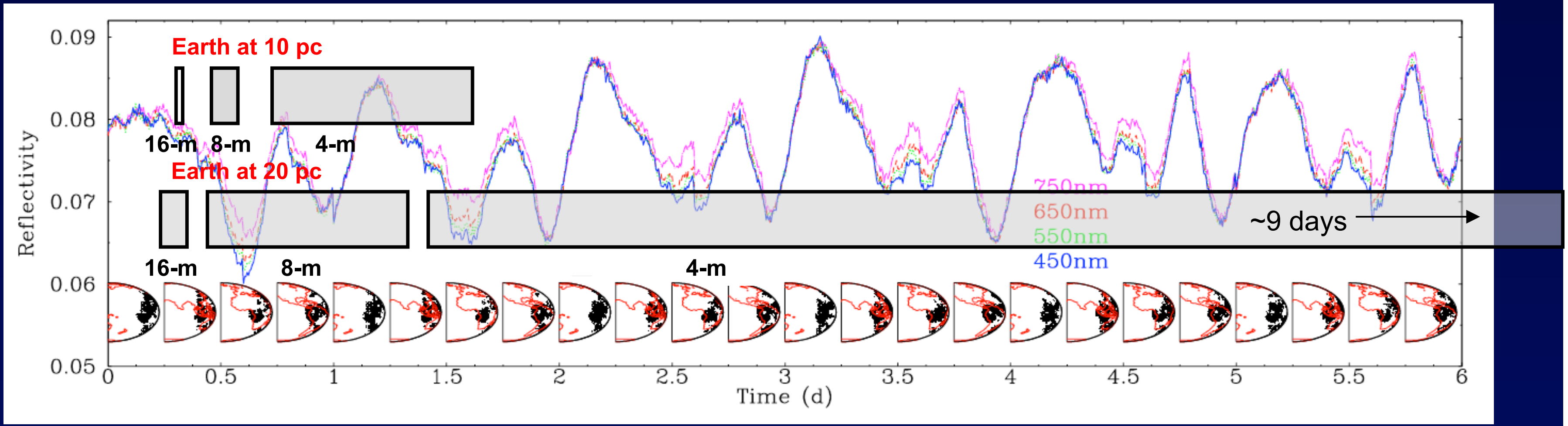
Reflectance ∝ (Planet Mass)$^{2/3}$
5 Earth-mass: 172 ksec on 8-m

Bkgd: 3 zodi
Contrast: 10^{-10}



Detecting Photometric Variability in Exoplanets

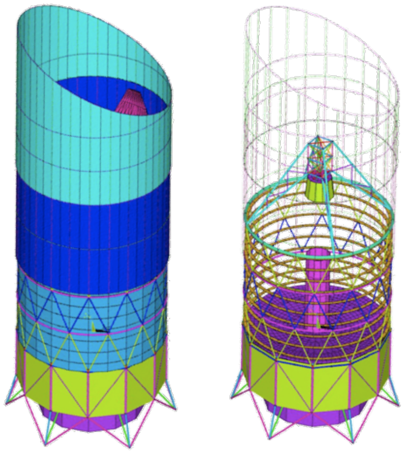
Ford et al. 2003: Model of broadband photometric temporal variability of Earth



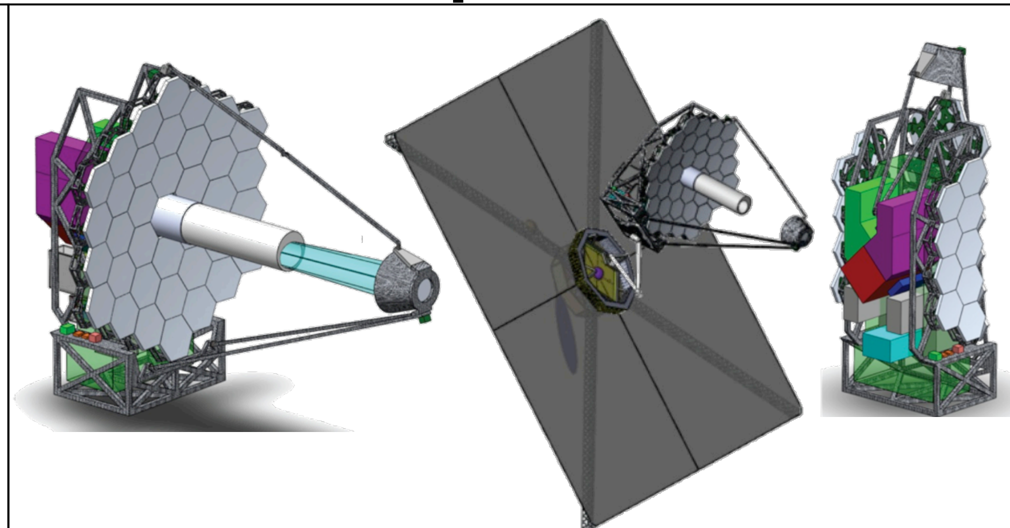
Require S/N ~ 20 (5% photometry) to detect ~20% temporal variations in reflectivity.

Need to achieve a single observation at this S/N in ≤ 0.25 day of exposure time in order to properly sample such variability.

ATLAST Concepts

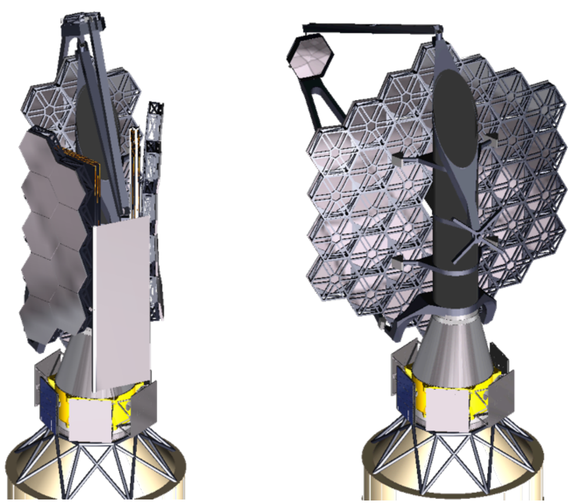


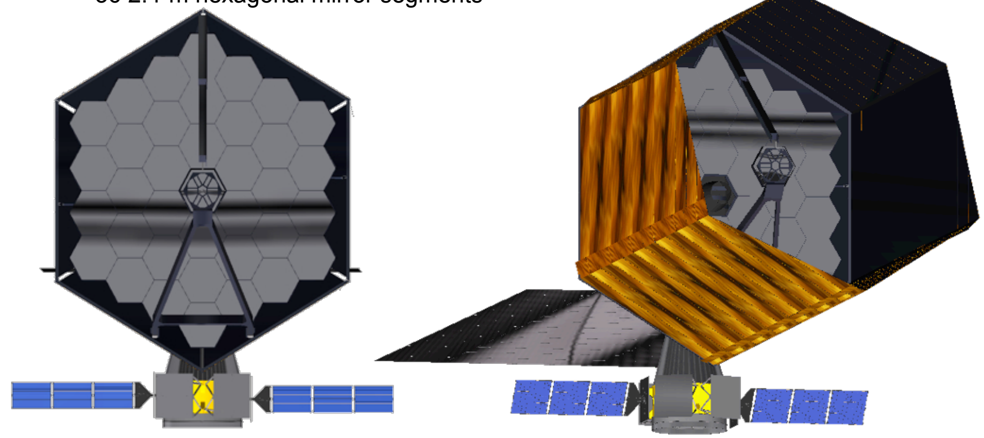
8-m Monolithic Primary
(shown with on-axis SM configuration)



9.2-m Segmented Telescope
36 1.3-m hexagonal mirror segments

16.8-m Segmented Telescope
36 2.4-m hexagonal mirror segments



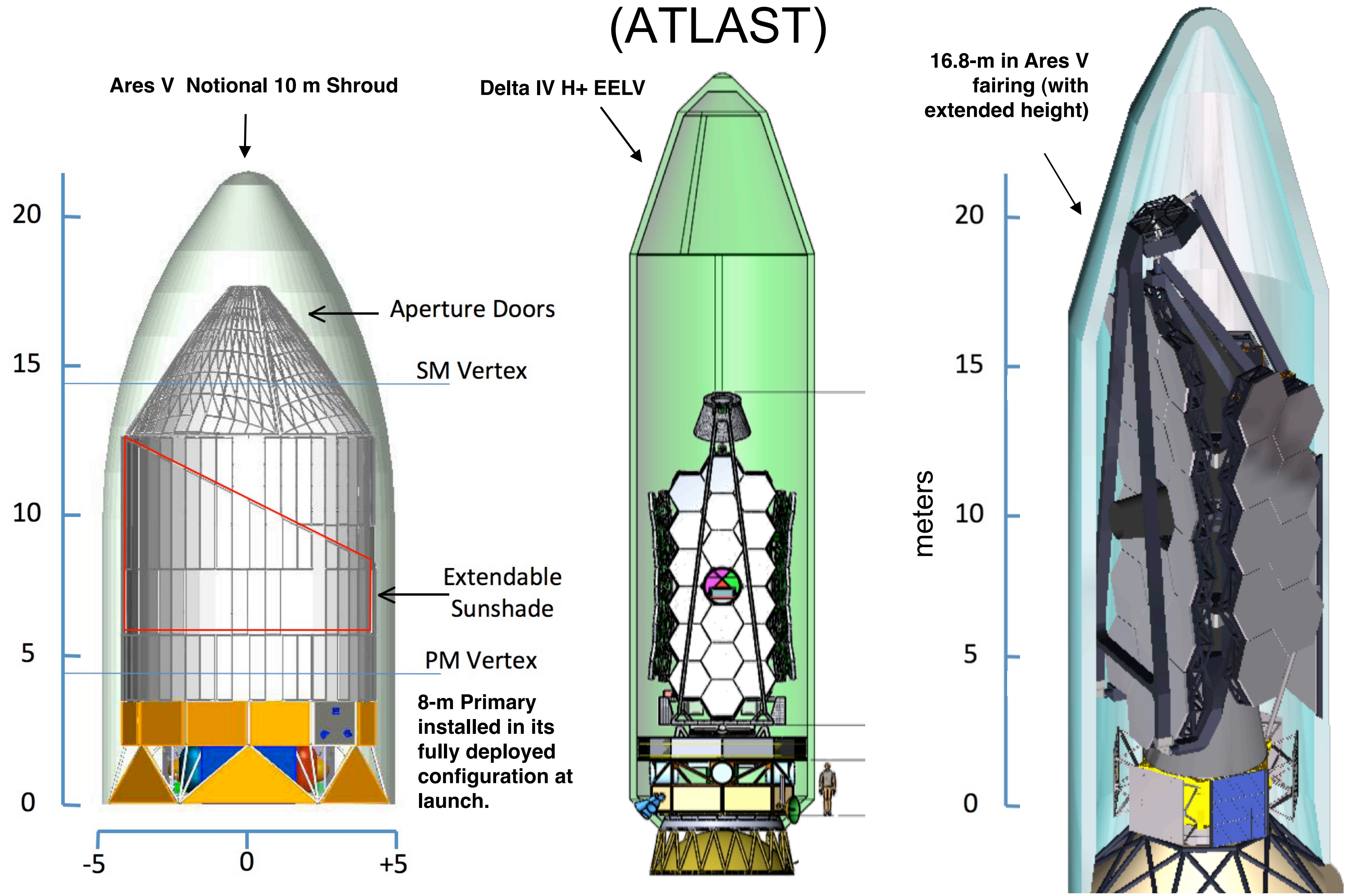


Studying two architectures: 8-m monolithic and (9.2-m, 16.8-m) segmented mirror telescopes

- Monolithic Primary
  - On and off-axis secondary mirror concepts investigated.
  - Off-axis concept optimal for exoplanet observations with internal coronagraph but adds complexity to construction and SM alignment.
  - Uses existing ground-based mirror materials. This is enabled by large lift capacity of **Ares V** cargo launch vehicle (~55 mT).
  - Massive mirror (~20 mT) has ~7 nm rms surface. Total observatory mass ~44 mT.

- Segmented Primary
  - Only studied designs with an on-axis secondary.
  - Requires use of (relatively) lightweight mirror materials (15 - 25 kg/m^2) & efficient fabrication.
  - 9.2m observatory has a total mass of ~14 mT (16.8-m has a total mass of ~35 mT).
  - **9.2-m** observatory can fly in EELV: **Does not require Ares V**.
  - Requires active WFS&C system.

Advanced Technology Large-Aperture Space Telescope (ATLAST)



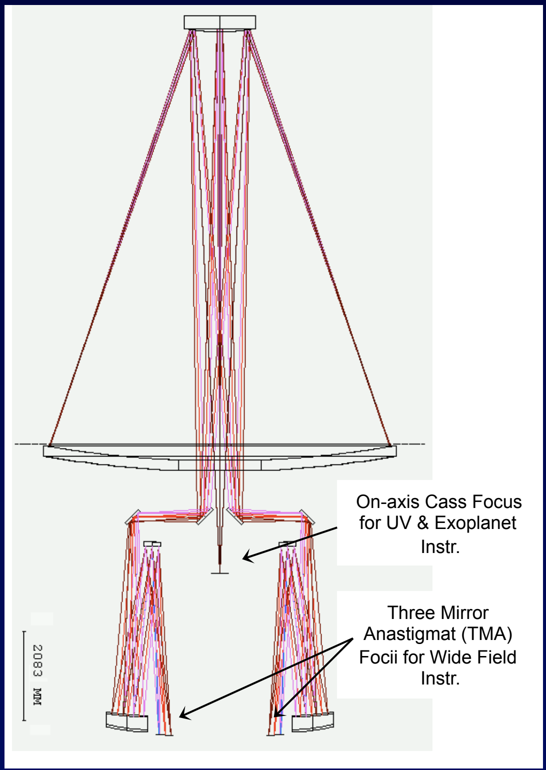
8-m Monolithic Telescope
Observatory dry mass = 44 mT

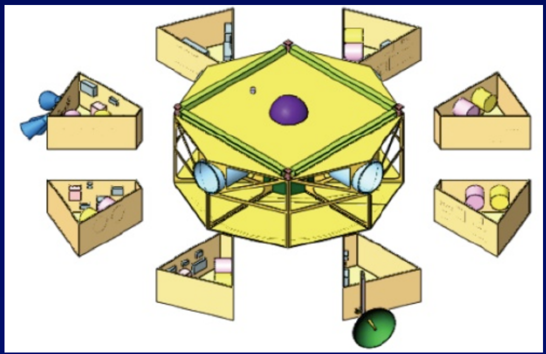
9.2-m Segmented Telescope
Observatory dry mass = 14 mT

16.8-m Segmented Telescope
Observatory dry mass = ~35 mT

Common Features for all Designs

- Diffraction limited @ 500 nm
- Designed for SE-L2 environment
- Non-cryogenic OTA at ~280º K
- Thermal control system stabilizes PM temperature to ± 0.1º K plus active OTA WFS&C system
- OTA provides two simultaneously available foci - narrow FOV Cassegrain (2 bounce) for Exoplanet & UV instruments and wide FOV TMA channel for Gigapixel imager and MOS
- Designed to permit on-orbit instrument replacement and propellant replenishment (enables a 20+ year mission lifetime)





Summary of the ATLAST Concepts

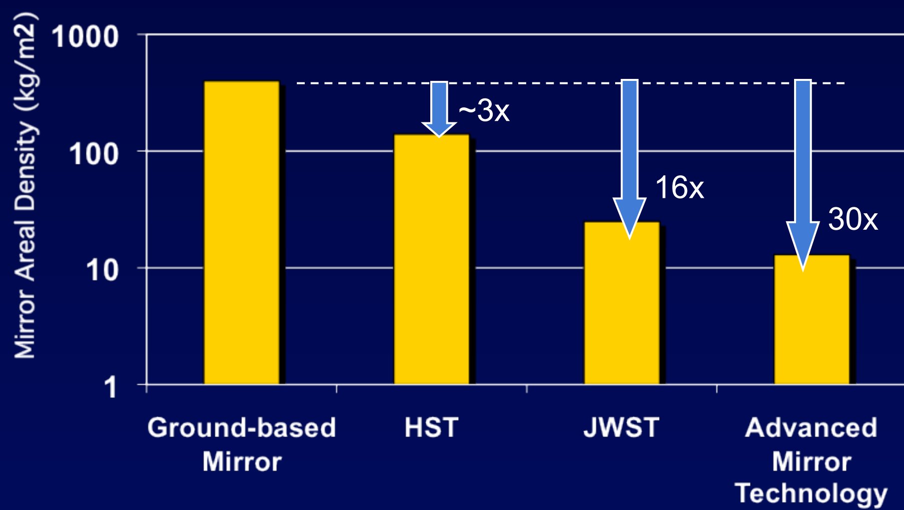
Aperture Size	OTA Type & Details	Ang. Resol. @ 500 nm	Sensitivity for R=5, SNR=10 Exoplanet in 100 ksec	3λ/D @ 500 nm	Starlight Suppression	Launch Vehicle
8m	Monolithic, High areal density ULE glass PM with 7 nm rms surface	15.7 mas	32.0 AB V mag (0.59 nJy)	39 mas	55m - 75m Starshade or Lyot or PIAA coronagraph (w/ off-axis SM or arched spider) or VNC	Ares V (or similar capacity vehicle)
9.2m	Segmented 36 x 1.3m AMSD glass, Active WFS&C	13.7 mas	32.5 AB V mag (0.38 nJy)	34 mas	55m - 75m Starshade or VNC	EELV: Delta IV Heavy with 7m fairing & 18mT lift
16.8m	Segmented 36 x 2.4m Actuated Hybrid Mirror, Active WFS&C	7.5 mas	33.8 AB V mag (0.11 nJy)	18 mas	70m - 90m Starshade or VNC	Ares V (or similar capacity vehicle)

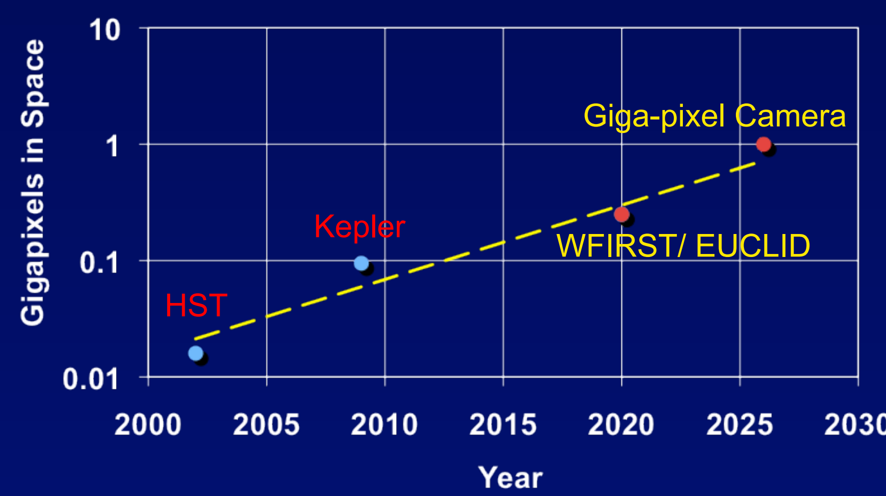
VNC = Visible Nulling Coronagraph

Key Technologies Needed for ATLAST

Technology Development for:

- Starlight Suppression Systems:
  - Hi-contrast Coronagraphs
  - External Occulter
- Optical Telescope Assembly
  - Advanced WF Sensing & Control
  - Fully Active Optics
  - Lightweight Mirror Materials
  - Lightweight Mirror Fabrication
  - Milli-arcsecond pointing control
- Gigapixel Detector Arrays
  - Photon-counting Detectors
  - High Efficiency Dichroics
  - High Efficiency UV coatings
- Systems Modeling & Verification
- Disturbance isolation systems
- Autonomous Rendezvous & Docking





Starlight Suppression

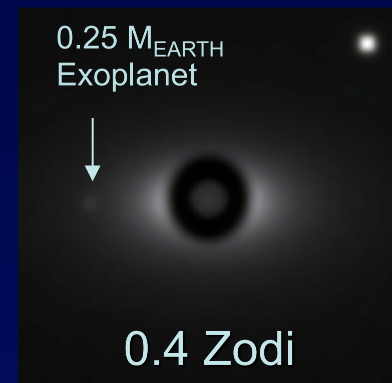
- Characterizing terrestrial-like exoplanets (<10 M_{earth}) is a prime ATLAST scientific objective.
- Challenge: how do we enable a compelling terrestrial exoplanet characterization program without:
    a) making the optical performance requirements technically unachievable for a viable cost (learn from TPF-C) and
    b) seriously compromising other key scientific capabilities (e.g., UV throughput).

Starlight Suppression Options: External Occulter: “Starshade”

4m 10m 16m

Images courtesy of Phil Oakley & Web Cash 2008, 2009

ATLAST-9m with 55-m Starshade:



Simulations of exosolar planetary systems at a distance of 10 pc observed with an external occulter and a telescope with the indicated aperture size. Planet detection and characterization become increasingly easier as telescope aperture increases. The challenges of deploying and maneuvering the star shade, however, also increase with increasing telescope aperture.

ATLAST Starshade Parameters:

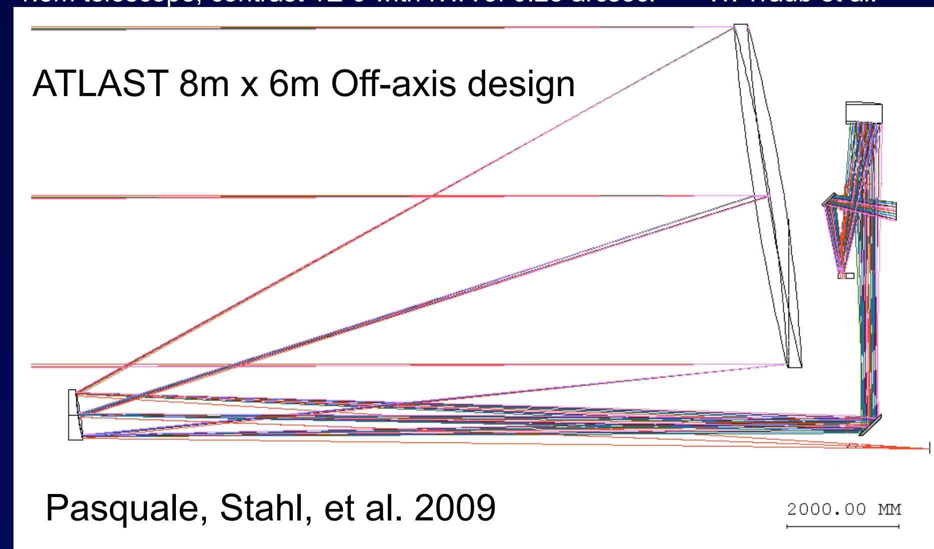
8m - 9.2m telescope: IWA = 58 mas, 55m shade @ ~80,000 km
IWA = 40 mas, 75m shade @ ~155,000 km
16m telescope: IWA = 40 mas, 90m shade @ ~185,000 km

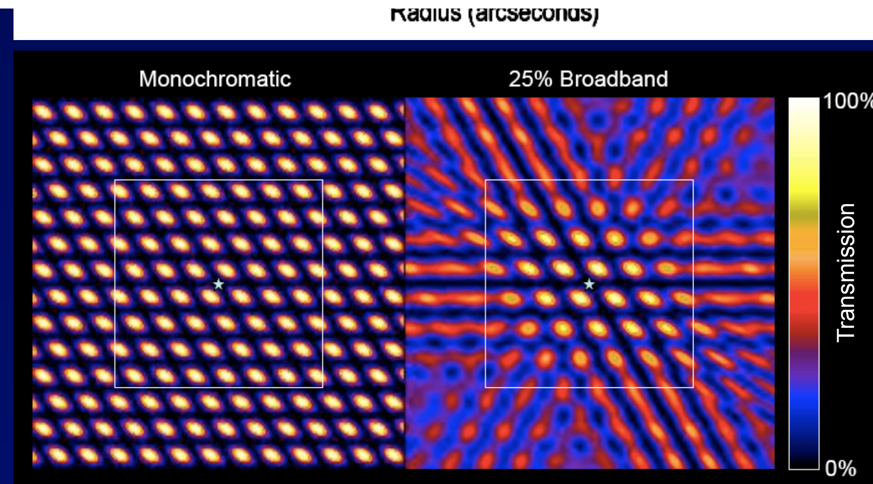
Starlight Suppression Options: Internal Coronagraphs

- JPL's High-Contrast Imaging Test-Bed (HCIT) has demonstrated sustained contrast levels of < 10^{-9} using internal, actively corrected coronagraph. Require monolithic mirror and, usually, an off-axis optical design.

- Segmented optics introduce additional diffracted light. Visible Nulling Coronagraph (VNC) can, in principle, work with segmented telescope to achieve 10^{-10} contrast. VNC chosen as starlight suppression method for TMT as well as for EPIC and DAVINCI mission concepts.

1.8m telescope, contrast 1E-9 with IWA of 0.25 arcsec. W. Traub et al.



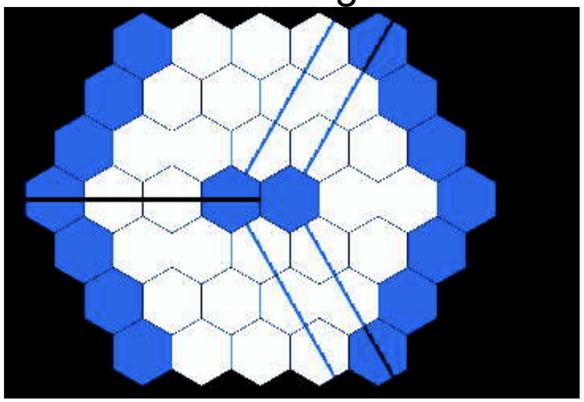


VNC Sky Transmission Pattern with 64 x 64 DM at 0.68 - 0.88 microns .
Credit: J. Krist, JPL

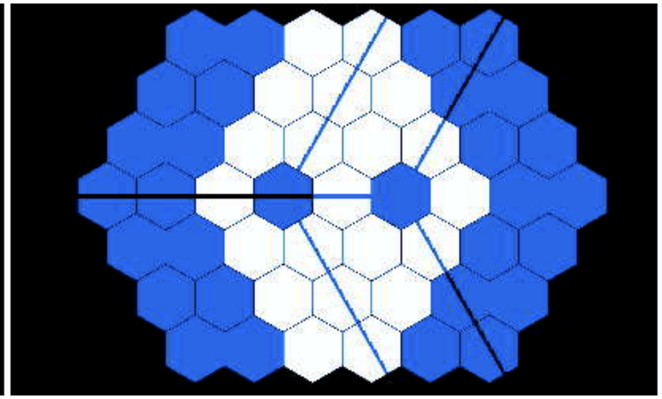
VNC Shears Pupil

Destructively Interferes Overlap Region

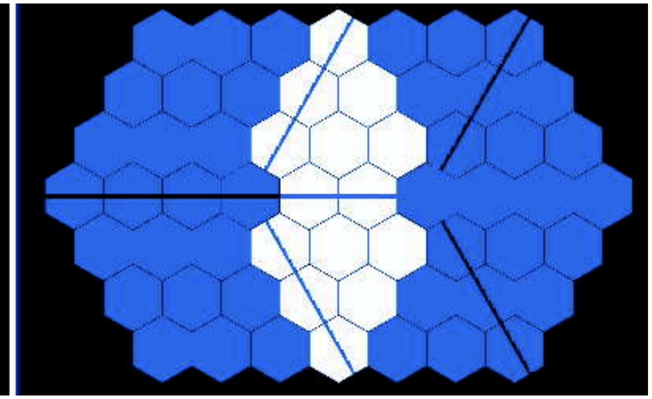
X Shear - 1 segmt



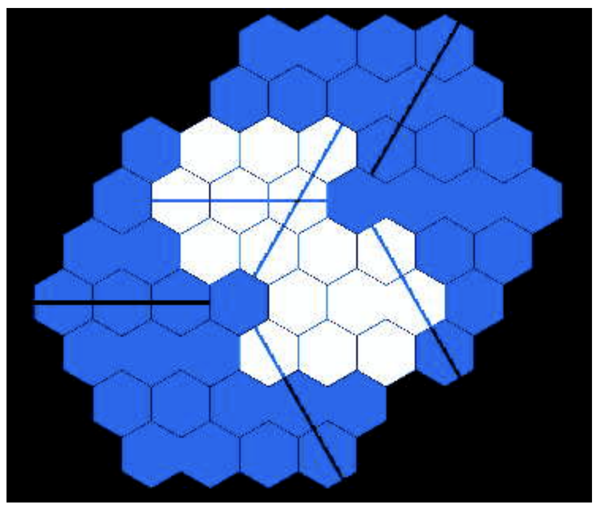
X Shear - 2 segmt's



X Shear - 3 segmt's

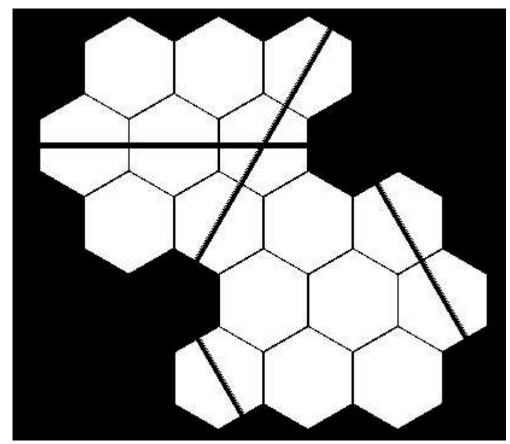


Y Shear



Shear by 2 segments in X
and 1.74 segments in Y
Reduces aperture to 44%

VNC is not elegant.
But, in principle, it does work
with a segmented aperture.



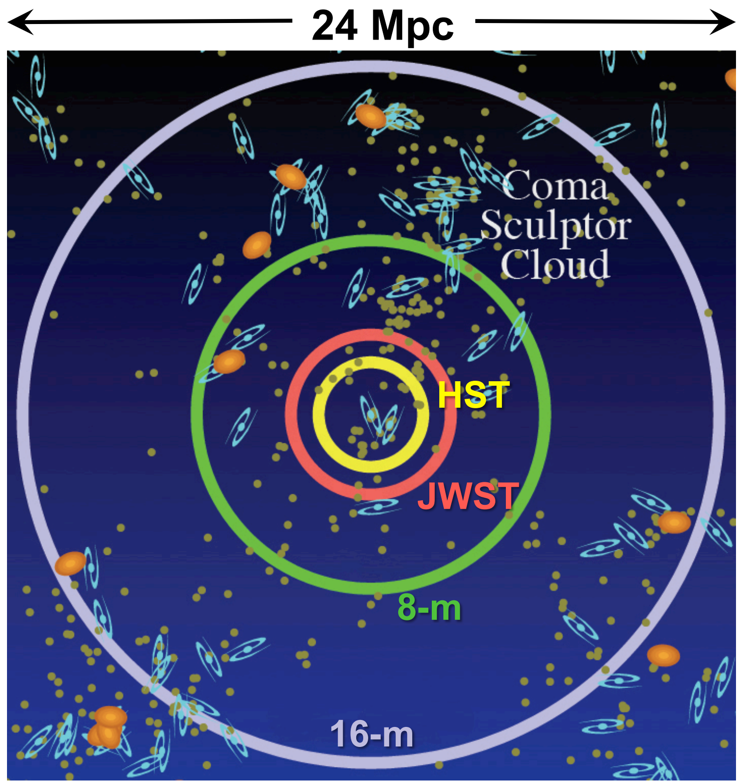
Effective Aperture
16 / 36 = 44% of full aperture

My Prioritized ATLAST Technology Development Wish List for 2011 - 2016

1. meter-class starshade demonstration of 10^{10} suppression
2. VNC demonstration of 10^{10} suppression
3. meter-class light-weight mirror technologies that achieve surface rms ~10 nm or less
4. Mirror actuator with sufficient precision for WFS&C at 500 nm (4 x better than JWST)
5. Improved UV coatings (better uniformity and efficiency)
6. Visible/NIR photon-counting detector arrays
7. Three-segment telescope testbed with fully active WFS&C that achieves diffraction-limited performance at 500 nm
8. Demo of disturbance isolation system in space environment (could be done on ISS)
9. Larger heavy lift launch vehicle (with wide fairing)
10. On-orbit autonomous servicing capability

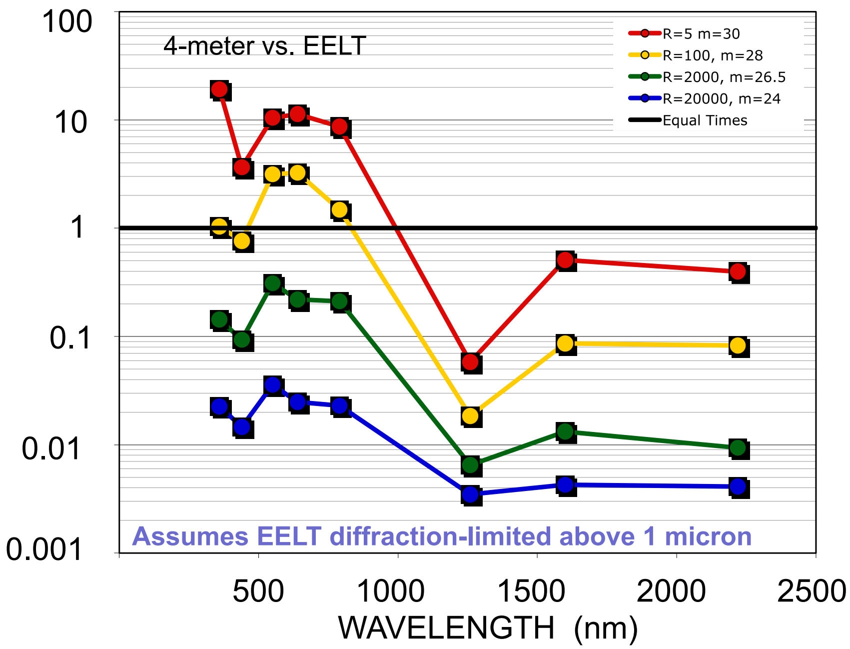
Large UVOIR telescopes are required for many other astrophysics research areas

- Precision stellar ages in external galaxies: need MSTO → Detect solar analog stars → 35 AB mag at 10 Mpc (S/N~5)
- Galaxy formation & evolution: map 3D distribution of intergalactic gas (SNR=20 high resolution (R=20,000) UV spectroscopy of quasars down to FUV mag = 24)
- Formation of structure in the universe; dark matter kinematics (10 km/s @ 60 kpc: 40 micro-arcsec/yr)
- Origin and nature of objects in the outer solar system (UV spectroscopy of outer planet atmospheres)



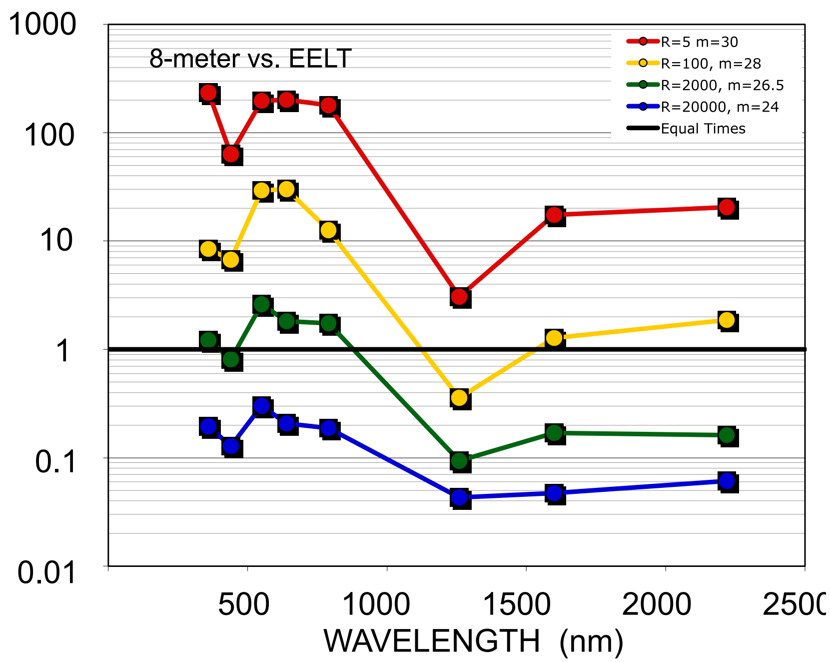
A "life finder" telescope will clearly be a multi-billion dollar facility - ***support by a broad community will be needed if it is to be built***.

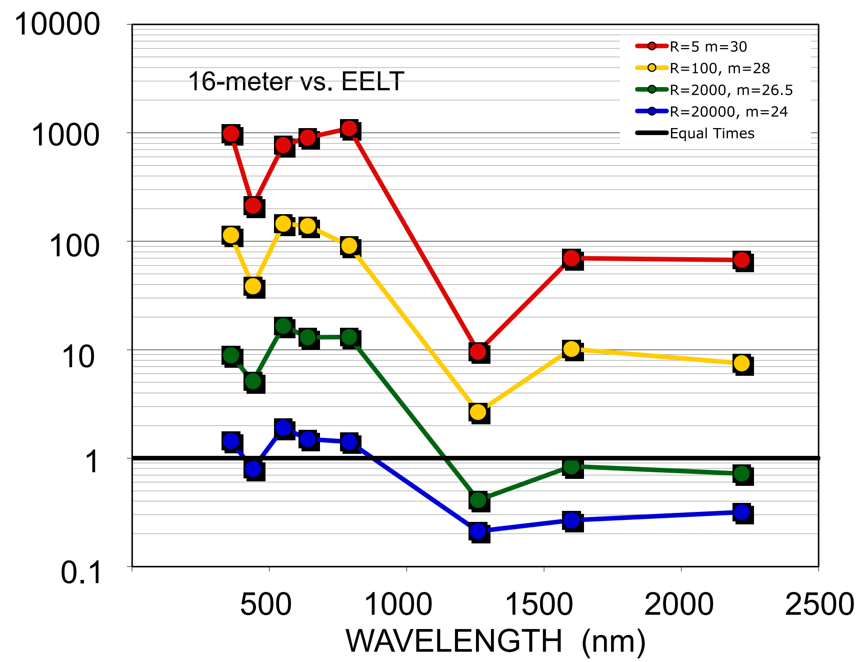
S/N=10 Time Gain Comparison



A 4-meter space telescope in the post-JWST / EELT era (ca. 2030) is *not likely to be* competitive in the arena of general astrophysics **(except in UV)**. An 8m – 16m telescope maintains unrivaled capabilities across a broad UVOIR wavelength and spectral resolution range.

4m @ 500nm = 31.5 mas	16m @ 500 nm = 7.9 mas
8m @ 500nm = 15.7 mas	42m @ 1200 nm = 7.2 mas





The Way Forward …

- Exoplanet characterization (spectroscopy) is the ultimate scientific goal – addresses question “Are We Alone?”
- An exoplanet mission that can answer this definitively requires a large star sample and hence at least an 8-meter aperture.
- Drivers in stellar and extragalactic astrophysics also point to the need for UVO space telescope with an aperture of *at least* 8-meters.
- Divided, neither community may get their mission before the 2030s. Together, it will be the most compelling mission of the 2020 era.